SPATIAL VARIATION OF DWELL TIME INDUCED BY A HYPERVELOCITY IMPACT.

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Introduction: A hypervelocity impact produces a shock wave which is followed closely by a rarefaction of release wave. The dynamics of the impact and passage of these waves determine the duration that material spends at high pressure which is also known as the dwell time. Laboratory studies can estimate the dwell time of material based on the observed size of high pressure polymorphs and their growth rates [1, 2], the cooling time of shock melt veins [3], and diffusion of various elements [4]. Dwell time has been used to infer size of impacts that ejected Martian meteorites through the following simple formula e.g. [1, 3, 4].

$$\tau_0 = D_{imp}/v_{imp}. \quad (1)$$

Bowling et al.[5] argue that this relation is unphysical and based on a misconception of shock rise time put forward by [6], where rise the time it takes for material being compressed by a shock to reach its peak pressure. The simulations of [5] show that for material ejected above martian escape velocity the dwell time varies by orders of magnitude and can be 100 times lower than implied by Eqn 1. However, [5] focused on the fastest ejecta in the near surface zone of irregular reflection where the shock and rarefaction are coincident, which is likely to have the lowest dwell times. To better understand the dynamics of impact cratering, we are working to extend the work of [5] to explore the spatial variation of dwell time throughout the target.

Modelling: Following [5] we simulate an impact on a Mars-like target, using the iSALE-2D shock physics code, which is based on the SALE hydrocode solution algorithm [7–11]. We simulate the impact between 10 km diameter, spherical basalt impactor and basalt target with high resolution (5m per cell or 1000 cells per projectile radius). The material properties of basalt are controlled by the ANEOS equation of state[12]. Pre-impact porosity is not considered in the imapctor or target. Our initial work is focused on a vertical impact at 13.1 km s^{-1}, the mean impact velocity on Mars[13]. We insert Lagrangian tracer particles into the simulation saving data at a interval of 10^{-4} s. Here we consider dwell time as the time material spends above a pressure of 1 GPa.

Results: The figure 1 and figure 2 show how the dwell time varies across the target in linear and log scale. The tested region extends 300 m vertically and 3.5 – 6.5 km horizontally from the impact point. It is clear that the dwell time strongly depends on the location in the target and it ranges from 7 ms to 529 ms. Outside the footprint of the projectile, the dwell time increases with depth. This makes intuitive sense since it will take longer for the rarefaction, generated when the shock reaches a free surface, to reach this deeper material. The dramatic drop in dwell time in the near surface comes from the unusual condition the zone irregular reflection, where the shock and rarefaction, which can travel faster than the shock through already shocked material, are coincident [14, 15]. It is for these same reasons that the dwell time changes dramatically with depth near the surface, but changes more gradually deeper in the target.

The yellow wedge-shaped characteristic in Figure 2 near X = 5 km may be due to the complex interplay between shock generation and propagation near the edge of the impactor. Because the impactor cannot be treated as a point source in this simulation, the area of impact increases as the simulation progresses. The geometry of the free surface is complicated and evolves as the impact progresses and the imapctor penetrates the target. The complex interaction of the shock with the free surface, which generated the rarefaction, ultimately produces this wedge-shaped feature.

The dwell time in the tested region varies significantly and shows a strong dependence on the location in the target. Eqn 1 predicts that the dwell time for a spherical impactor with a diameter of 10 km that moves in 13.1 km s^{-1} is $\tau_0 \approx 763$ ms. Eqn 1 gives an order of magnitude estimation for the longest dwell time in the target region considered here. This is not surprising since the planar impact approximation the suggests that the dwell time may reach a few times τ_0 near the point of impact [16].

Discussion and Ongoing work: The analyzed target area is much larger than the region of material ejected above Martian escape velocity, but still only represents a small fraction of the entire target. We are currently running simulations to extend our analysis to a much larger portion of the target. We also plan to simulate impacts at different speeds to explore the dependence on impact velocity. Bowling et al. [5] found that the dwell time for the fast ejecta is relatively insensitive to impact velocity while the dwell time given by Eqn 1, which should be a reasonable approximation close to the point of impact, is inversely proportional to impact velocity. Finally, we plan to also determine the rise time of the material. This will give us deeper insight into the factors affecting dwell time.

In this study, we only consider vertical impact. However, most impacts occur at oblique incidence[17]. At

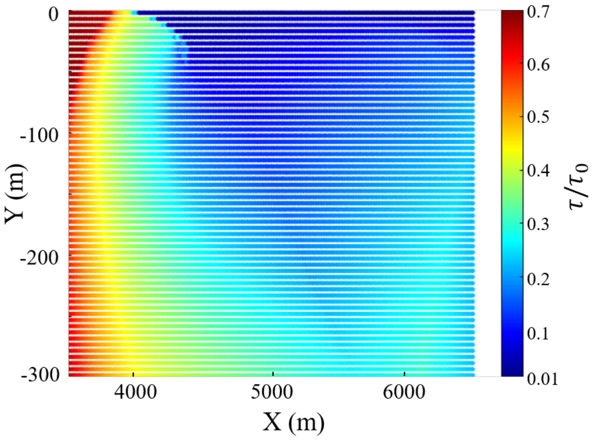

Figure 1: Provenance plot of the variation of dwell time in target. Lagrangian tracers are plotted at their original locations and colored according to their normalized dwell time (τ/τ_0) as indicated by the color bar. The X and Y axes represent the horizontal and vertical distance from the impact point, respectively. Note the linear scale for the normalized dwell time.

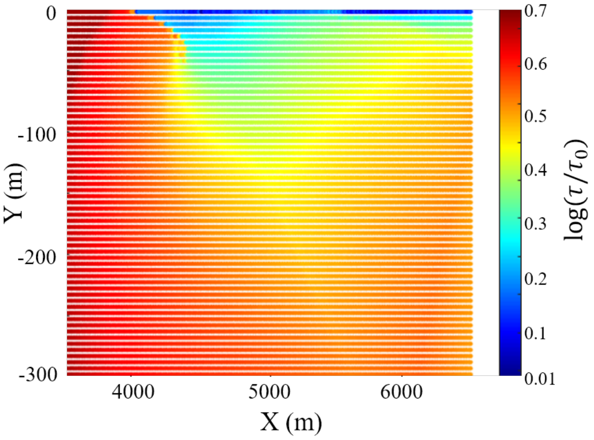

Figure 2: Same as figure 1, but with a logarithmic scale for the normalized dwell time.

a given impact velocity, oblique impacts have a longer contact and compression timescale due to the smaller vertical component of the impact velocity.This longer contact and compression timescale likely also enhances the dwell time of material. Furthermore, [18] noted that an oblique impact is able to excavate high speed ejecta from deeper in the target than a vertical impact. Because dwell time tends to increase with depth, this could result in higher dwell times. Robust conclusions regarding the effect of impact angle on dwell time require high-resolution three-dimensional impact simulations, which may be the subject of future work.

Although the main goal of this study is to better understand cratering dynamics, our work may have several important applications. Meteorites sourced from small bodies are on average ejected at lower speeds and Mars' escape velocity. Thus, we need to explore dwell time in more of the target to understand what the dwell time of these meteorites might tell us. Moreover, martian meteorites may have experienced multiple shock events. Thus, understanding spatial distributions of dwell time over the entire target could be useful for untangling the complex history of some martian meteorites. Lastly, dwell time estimates could be made for terrestrial craters to help us better understand impact processes including the distribution of dwell times within the target.

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